Bridging the STEM + Arts (STEAM) Gap for Socially Inclusive Research and Innovation: Evidence from Low and Middle-Income Countries

Pascale Saint-Denis | Research Award Recipient
Education and Science | International Development Research Centre

Abstract

As scientific knowledge production and cutting-edge technologies continue to advance rapidly to generate prospects of economic growth, employment opportunities and improved health care, we are also seeing outcomes of accentuated social inequities in vulnerable groups in low- and middle-income countries (LMICs). Such outputs and innovations have uniquely impacted women of intersecting identities and backgrounds, and their representation in the global workforce in the science, technology, engineering, and mathematics (STEM) fields remains low. These longstanding issues demand a shift in approaches to conducting STEM research and recruiting research teams that can reflect the diversity of lived experiences within societies. The current study investigates the incorporation of the Creative and Liberal Arts in STEM (STEAM) research undertaken in LMICs to understand how it can impact the engagement of individuals of diverse backgrounds, particularly women, and produce socially relevant knowledge and innovations. Through semi-structured interviews and an online survey with STEM scientists across Africa and South America, this report elucidates the benefits and challenges of STEAM research, the compositions of STEAM teams and their dynamics, and the integration of gender in such projects. Finally, the study discusses future pathways for the STEAM research agenda and recommendations to move towards better supporting STEAM initiatives and researchers.

Word cloud of abstract

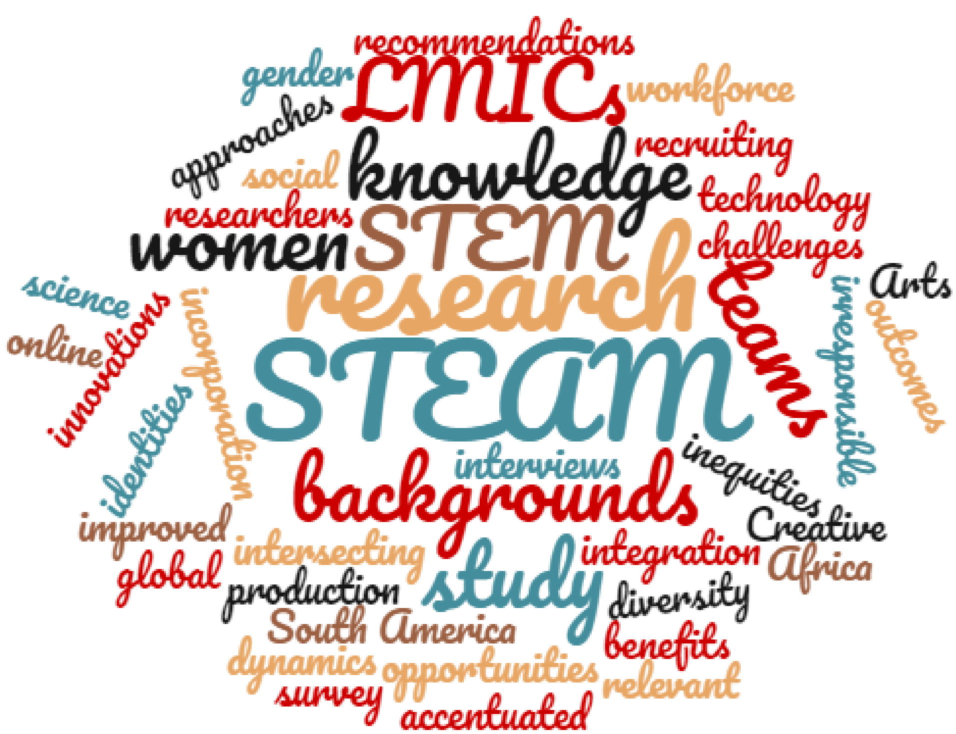

Table of contents

1. Introduction

1.1 *Integrating the Arts into STEM – What is STEAM?*

The 'STEAM' acronym that bridges 'Science', 'Technology', 'Engineering', 'Arts', and 'Mathematics' is a recent term coined in the past decade which was especially brought to light as the United-States passed the *Every Student Succeeds Act* in 2015, which aimed to provide students with a well-rounded and interdisciplinary education (Ludwig, Boyle & Lindsay, 2017). Originating as a pedagogical framework for K-12 education, elements and approaches from the Arts began to be incorporated into STEM curricula design to enhance creativity and problem-solving abilities (Colucci-Gray, Cooke, and Gray 2017; Land, 2013). Early evidence of applying STEAM approaches in higher education institutions from high-income countries has been shown to improve the retention of women in STEM degrees (Wajngurt & Sloan, 2019), make students adaptable to the rapidly changing landscape of science and technology (Universities Canada, 2016), and shape competitive students for the STEM workforce (Segarra et al., 2018).

As the body of literature promulgating the benefits of applied STEAM education continues to grow, there are also scholars that caution against over-emphasizing expectations of positive outcomes from STEAM initiatives and who advocate for the Arts to be valued in their own rights and not only as an enhancing agent (Ghanbari, 2015). This debate stems from the notions that creativity and innovation are not exclusive to the Arts, as they are equally intrinsic to the sciences (Zimmerman, 2017). Moreover, the significant variation in the extent to which the Arts are integrated is characterized as a substantial challenge, as demonstrated by an integrative review on STEAM education performed by Perigrat & Katz-Buonincontro (2019), which reveals that there are deviating opinions among scholars when referring to the concept of STEAM. There is also a lack of understanding and clarity of the 'A' in STEAM and the degree to which the Arts engage with STEM disciplines. For instance, commonly used terms to describe the relationship between STEM and Arts discipline include "arts-infusion, arts-integration, merging, connecting, combining and embedding" (Perigrat & Katz-Buonincontro, 2019, p.38). This broad range of terms suggests that there may be a misalignment of *how* and *why* arts approaches are applied in STEM education.

STEAM research in the context of this study refers to the integration of concepts, methods and perspectives from the Creative Arts (visual arts, performing arts and literary arts) and the Liberal Arts (social sciences and humanities) in STEM research. The deep division between the Arts and sciences in the past half-century has led to a notable gap in the literature of overarching studies investigating the benefits and challenges of the application of STEAM research, especially in low- and middle-income countries (LMICs), which suggests that it continues to be an emerging topic. Filling this gap is critical as using STEM research methods alone will not be sufficient to take on the STEM-related multi-faceted challenges with which these societies are faced (Lachman, 2018). This study provides a significant opportunity to advance the understanding of STEAM research and innovation in LMICs, specifically how they may impact the inclusion of underrepresented groups in STEM and produce socially responsible outputs.

1.2 *Trends of underrepresented groups in STEM in LMICs*

The gender gap of women in STEM fields is a global concern as they only make up approximately 29% of all STEM researchers worldwide (UNESCO, 2019). National and regional figures, however, significantly vary. Regions such as Central Asia and Latin America and the Caribbean are among the global leaders in women's STEM representation, attaining 48.3% and 45.1% participation, respectively (UNESCO, 2019). Gender parity in the STEM workforce has been reached in several countries in the regions, such as Guatemala (53.2%), Argentina (53%), Kazakhstan (52.3%), and Panama (51.8%), and women are even dominating as scientists in Venezuela (61.4%) (UNESCO, 2019). Peru (29.9%) and Tajikistan (38.4%) hold the lowest figures of women scientists in their regions and are still above the global rate (UNESCO, 2019). The Arab States (41.5%) are not far behind in achieving equal representation of women in the STEM workforce, but there is substantial variation within the region, as demonstrated by the difference between Kuwait, the country with the highest rate of representation at 52.6%, and Jordan, the country with the lowest rate at 21.4%. (UNESCO, 2019). Sub-Saharan Africa remains slightly above the global average, with 31.8% of STEM scientists being women, but there are once more discrepancies amongst regional countries (UNESCO, 2019). Countries such as Burundi (14.5%), Ethiopia (13.3%), Guinea (9.8%), Togo (9,3%), the Democratic Republic of Congo (6.7%) and Chad (4.8%) are experiencing amongst the lowest in contrast to Mauritius (48.9%) and South Africa (45.1%) that have almost reached an equal share of gendered representation (UNESCO, 2019). Finally, there is East Asia, with 23.9% of STEM researchers being women and South and West Asia at 18.5% (UNESCO, 2019). Myanmar ranks the highest in the world with a remarkable dominance of 75.6% women in STEM, while Bangladesh (14.0%), India (13.9%) and Nepal (7.8%) are amongst the lowest (UNESCO, 2019).

Figures of equal representation may be misleading, however, as there are important disparities across STEM disciplines. For instance, female researchers remain consistently least present in what are considered as the "hard sciences", such as physics, computer science and engineering, where mathematics plays a fundamental precursor role (UNESCO, 2017c). Other STEM fields are gender-balanced, some even dominated by women, such as in the life sciences, biology, medicine and health sciences (Huyer, 2015). The field of agriculture is also witnessing a shift in gender representation as women are slowly being integrated and are starting to assume leadership positions. However, this phenomenon of overrepresentation of women in specific disciplines, which is referred to as the feminization of the qualified workforce, has been found to be associated with a devaluation of status and remuneration in contrast to male-dominated fields (Miller, 2016).

Additionally, the collection of sex and gender-disaggregated data within science, technology, and innovation (STI) systems poses a significant gap in the literature (UNESCO, 2107b). There is also a lack of literature that documents intersecting factors of identities in the STEM workforce, such as class, caste, race, sexuality, Indigeneity, disability, motherhood, and more, especially in LMICs' contexts. This type of data collection is paramount in coordinating targeted efforts to integrate women in STEM because they are not a monolith and face distinct barriers to entering and remaining in the field depending on their identities and experiences (Engendering Success in STEM, 2019). These gaps must be addressed to identify and tackle the systemic barriers that hinder inclusive access to opportunities in STEM work fields.

1.3 *Attrition of underrepresented groups in STEM and factors influencing participation*

Women have been observed to leak out of the STEM pipeline at a more frequent rate than men (Blickenstaff, 2005), particularly in tertiary education as they transition from the master's to Ph.D. level, where participation drops from 53% to 43% (Huyer, 2015). Subsequently, the presence of women in STEM reaches its highest attrition levels, as only 29% enter the workforce. Previously, the low participation of women in STEM was rationalized by their cognitive differences that were thought to result in inferior mathematics and scientific abilities, which has consistently been disproved (Hyde & Mertz, 2009; Spelke, 2005), thereby prompting the question: How can the longstanding issue of underrepresentation of women in the STEM labour force be explained?

The low representation of women in STEM in the later stages of education and early career stages is likely tied to their educational experiences as young girls. Asia well exemplifies this link as countries where boys are out-performing girls experience a lower representation of female scientists, such as the Republic of Korea (21.2%), and the opposite is true in countries such as Thailand (53.2%) and Malaysia (48.2%) where girls are earning higher learning achievements than boys (UNESCO, 2017c; UNESCO, 2019). Lower scores in mathematics and science subjects are also understood to be related to anxiety and a lack of confidence regarding scientific and mathematic abilities (OECD, 2015). The difference of interest in these subjects is more likely attributable to regional and national socio-economic and cultural factors. Lack of access to education, inadequate education systems, and imposed gender roles and expectations are important factors that can impede girls' general education, impacting participation, interest, confidence, and performance in science and mathematics in primary school (UNESCO, 2017a). By the time girls reach secondary education, when they have increased agency to shape their educational pathways to pursue post-secondary education, their interest in STEM disciplines has already been undermined, and these are no longer considered as options.

However, reaching equal representation is not necessarily a priority for all regions; in some contexts, effective inclusion has gained prominence over parity. Certain countries that have attained or are close to attaining an equal share of female STEM workers, such as various countries in Latin America for example, are beginning to move beyond solely increasing participation towards addressing questions of equity of work conditions for female scientists in producing scientific knowledge (IDRC, Colciencias & OCyT, 2018). Attempting to achieve gender parity in STEM may be crucial for advancing gender equality, but it does not necessarily equate with an equitable work environment and accessible work opportunities. As women and girls progress in STEM education and the workforce, they are consistently subjected to systemic barriers shaped by norms and structures that negatively impact their capabilities and empowerment. Gendered social norms and behaviours typically materialize through discriminatory hiring practices (Eaton et al., 2020) and hostile organizational climates (Settles et al., 2006). Further, women are less likely to persist in fields that maintain particularly strong gender stereotypes, such as physics, engineering, and computer science (Cheryan et al., 2017), where they have low chances to earn lab manager positions (Moss-Racusin, 2012) or tenure-track assistant professorships (Eaton et al., 2020). Moreover, structural barriers, such as inadequate maternal leave policies, play an important role in provoking women to leak out of the pipeline (Ceci & Williams, 2011; Okeke et al., 2017).

This acute attrition of women in STEM that takes place in higher education and the transition to the workforce is a cause for immense concern in LMICs because the obstruction of women being represented in positions of leadership and knowledge production effectively "[impeding] on innovation and economic advancement as large swaths of talent are underutilized" (New York Academy of Sciences, 2014, p. 5). As the knowledge of a significant portion of the population is not being harnessed, the capacity of LMICs to optimize economic growth, improve gender equality and access to quality education is thereby undermined. To address the above-mentioned systemic barriers in LMICs, it is imperative that government agencies, science granting councils and STI institutions move towards developing inclusive policies and practices, investing in training programs aimed at developing female STEM researchers' capacities, and incorporating sex and gender considerations to diversify STEM fields (Nielson, Bloch & Schiebinger, 2018; Nikoleyczik, 2012; Okeke et al., 2017; Wang & Degol, 2017).

1.4 *Inclusive research, technology, and innovation*

As low- and middle-income societies continue facing complex socio-economic and political challenges, STEM innovations that propose solutions are forcing us to scrutinize the power and bias that accompany them. Scientific knowledge production has a long history of systemically excluding individuals of intersecting identities as both knowledge producers and subjects, much to the detriment of advancing innovation processes and results that adequately respond to societal needs, particularly those of such marginalized groups. Developing and generating socially responsible science goes further than merely looking to scientists to produce quality science, but rather they assume social responsibilities so that "research [may be] carried out in the name of society, as an expression and a reflection of the society's needs, interests, and priorities, and of the expected or presumed consequences of the research findings" (Bird, 2014). White abled-bodied men from high-income countries have typically been the reference for understanding all bodies and have historically been considered as the most important voices in science, which challenge this notion of socially responsible science and has resulted in technological designs and scientific practices suited for select groups (Klein, 2019). Although there has been a growing interest in gendered innovations (European Commission and Directorate-General for Research, 2013; Schiebinger, 2014) and using gender-sensitive approaches to medicine (Klinge, 2010), health (Bauer, 2014; Fehrenbacher & Patel, 2019; Kelly et al., 2009), climate change (Weatherhead, Gearheard & Barry, 2010), information, communication and technology (ICT) (Webb & Young, 2005), neuroscience (Nikoleyczik, 2012; Roy, 2016), and engineering (Udén, 2017), neither gender nor intersecting factors had been rigorously incorporated into STEM research until the past few decades. These oversights have had substantial consequences on the safety and accessibility of innovations for marginalized groups (Tannenbaum et al., 2019).

As technological developments continue to advance at a rapid pace, more transdisciplinary and diverse research teams using approaches from the Arts are demanded to learn from and improve the shortcomings of previous technological production. From ill-fitting personal protective equipment for women (Trades Union Congress, 2017) to car crash test dummies that had not initially accounted for the diversity of human bodies (Kahane, 2013), these innovations and others have demonstrated how exclusionary and disciplinary approaches in STEM can generate dangerous consequences for specific populations. Cutting-edge technologies taking the world by storm are raising particularly crucial questions of ethics and equity. The use of nanotechnology in LMICs, for instance, has been a controversial topic as its various applications have been characterized as catalysts for addressing development challenges in water, health and energy sectors while also potentially widening socio-economic gaps (Ivernizzi & Foladori, 2005). Biotechnology in medicine is another example of an emerging disruptive technology that has pushed ethical boundaries and has the potential to aggravate inequities should social determinants of health be ignored (Harcourt, 2007)

Similarly, the rise of Artificial Intelligence holds prospects of economic growth and employment opportunities, but its applications have the power to exacerbate social inequalities in LMICs (Smith & Neupane, 2018). For example, AI has entered social media outlets that provide large public spaces for networks of social connections and news consumption. Platforms such as Facebook use AI to filter and censor hate speech and misinformation posted from its users, a system that has repeatedly showcased its serious weaknesses and deadly repercussions in highly polarized contexts. In Myanmar, the social media's AI failed to remove hate speech that perpetuated violent rhetoric towards the Rohingya ethnic minority, contributing to their genocide in 2017 (Miles, 2018; Serrato & Meyer-Resende, 2018). Similar situations also occurred within the past few years in Sri Lanka and India, where widespread misinformation and hate speech that was not censored from the platform inflamed violence against minority Muslim groups (Kamdar, 2020). Using disruptive technologies in such contexts requires an understanding and analysis of the socio-political context in which it is being used, which must be performed by the appropriate experts.

Additionally, various AI systems have been found to mirror human gender and racial biases in their algorithms, such as biased language that perpetuated harmful gendered stereotypes (Bolukbasi et al., 2016) and facial recognition software that fails to recognize specific facial structures and skin tones, particularly those of women with dark skin tones (Harwell, 2019). Eliminating these discriminatory biases is an urgent matter as AI systems are beginning to play a role in state surveillance (Feldstein, 2019), health care (Bresnick, 2018) and education (Marr, 2018). Providing access to equitable work opportunities in the STEM sectors to individuals of diverse backgrounds and equally considering their views are the first steps to begin holding accountable human biases (West, Whittaker & Crawford, 2019).

Diversity alone, however, will not be enough to challenge power in science and technology. Engaging and valuing the views of artists, ethics experts, gender experts, legal professionals, political scientists, sociologists and psychologists, among others, in the research, development and application of these technologies and innovations will also be paramount to mitigate and lessen their negative repercussions (Harcourt, 2008; Jensen, 2020; Tschopp, 2018). Therefore, the Creative and Liberal Arts have the potential to give a conscience and humanity to STEM by engaging with diverse, transdisciplinary teams that have the capacity to address persisting social inequalities rather than reinforce them (Jensen, 2020).

2. Research Objectives and Questions

This study seeks to contribute to the emerging subject of STEAM research outcomes by generating new knowledge and understanding of the STEM, Arts, social inclusion and responsibility nexus. Foregoing are the objectives and specific questions that guided this research:

Objective 1: To explore the extent to which the integration of the Creative and Liberal Arts in STEM research may be conducive to increasing the participation of individuals of intersecting identities in STEM, especially women of intersecting identities.

- Do STEAM teams make deliberate efforts to include individuals of diverse backgrounds, particularly women of diverse backgrounds?
- Are STEM research projects that integrate questions from the Arts more attractive to such individuals? Or rather, does their inclusion influence the decision to take on arts-based perspective, methods, and concepts?

Objective 2: To identify the opportunities and challenges of STEAM research initiatives in terms of producing socially responsible outputs in LMICs through multidisciplinary, interdisciplinary, or transdisciplinary collaboration.

- How are STEAM research teams composed in terms of expertise? How do the team members collectively work under a common framework?
- How does STEAM research differentiate itself from conventional STEM research?
- Do STEAM research questions, design, application and diffusion challenge existing power structures and inequality? If so, how?

3. Methodology

3.1 Conceptual Framework

This research adopts a gender-responsive approach as gender is a core focus embedded in the background and rationale, research questions, methodology and analysis (IDRC, 2019). Although this study does engage with questions of systemic and institutional root causes of inequality and power imbalances, it is not considered gender-transformative as it cannot yet be contextually applied in informing STI policies or institutional practices. Overarching studies on the benefits and challenges of STEAM research in LMICs remain low, and there is much more research to do in order for them to be influential and transformative.

Further, this research also considered intersecting factors of groups subject to discrimination due to their compounded lived experiences and identities of gender, ethnicity, race, class, caste, disability, motherhood, and more (Crenshaw, 1989). Such individuals are recurrently referred to in this report as 'individuals of intersecting identities' or 'individuals of diverse identities or backgrounds' not to erase or negate any identity (Bowleg, 2012). An active effort was made to synthesize literature on such participants to understand the diverse perspectives in STEAM research and their impact on their research. However, particular attention was given to the participation of women of diverse backgrounds in the sciences for this study per IDRC's mandate on allocating efforts to address systemic barriers impacting their integration into STEM and improving their representation and role as leaders (IDRC, 2017).

This study will also privilege the concepts of multidisciplinarity, interdisciplinarity and transdisciplinarity as advanced by Choi and Pak's in-depth literature review (2006) who put forward an interesting comparison to distinguish these team disciplinary approaches: multidisciplinarity is additive like a salad bowl as it refers to "different […] disciplines working on a problem in parallel or sequentially, and without challenging their disciplinary boundaries" (Choi & Pak, 2006, p.359). Interdisciplinarity is considered as interactive like a melting pot, which "brings about the reciprocal interaction between […] disciplines, necessitating a blurring of disciplinary boundaries" (Choi & Pak, 2006, p.359). Finally, transdisciplinarity is like cake as it takes on a holistic approach by "[involving] scientists from different disciplines as well as non-scientists and other stakeholders and, through role release and role expansion, transcends […] the disciplinary boundaries" to produce a "final product that is of a different kind from the initial ingredients" (Choi & Pak, 2006, p.359). These interpretations emphasize how disciplinary approaches are not synonymous as they are so commonly interchanged in the literature, but instead they are situated along a continuum and have different implications. These interpretations are relevant to understand how STEAM research teams that are inherently multi, inter or transdisciplinary are organized and carried out.

3.2 *Literature review*

This study incorporated an in-depth literature review executed through a Web search, applying keywords in search engines, forums, and media platforms. Academic articles, online content, and open access reports relating to STEAM research and education, inclusive STEM research and gendered innovations were gathered from this search. The purpose of the literature review was to situate the research and establish the foundation for knowledge by providing context and background, identifying the gaps and opportunities, and informing the online survey questions and the semi-structured interviews. The literature review was ongoing throughout the execution of this project.

3.3 *Primary Data Collection*

3.3.1 Research participant profile and sample strategy

The key informants recruited to participate in the study comprised of STEM researchers and scientists with nationality within low and middle-income countries who have experience in employing the Creative and Liberal Arts in their research in various capacities. This refers to STEM scientists who may have a background and expertise in the Arts and apply such artistic knowledge in their research or STEM scientists who have collaborated with experts in the Arts in research teams (i.e. STEAM teams). No specific country or region was chosen for this study as STEAM research continues to be an emerging topic in LMICs in general, and this study was utilized as an opportunity to capture the richness and diversity of STEAM research across regions.

The list of participants was compiled using a purposive sampling strategy based on the aforementioned participant profile. Snowball sampling proved to be effective in recruiting expert informants for interviews as extensive pre-existing networks of interviewees and referral contacts allowed for a more voluminous reach of respondents. However, this strategy did elicit a higher rate of interviewees from a few countries, limiting the intent to diversify participants' nationality.

3.3.2 Online survey

An online survey with open-ended questions was employed in an attempt to reach a high rate of participants to overcome travel restrictions and social distancing measures caused by the COVID-19 pandemic. However, this method only generated eight complete responses and four incomplete responses that were discarded and not included in the findings and discussion. Participants were required to complete an informed consent form before being granted access to the survey, which remained open from the beginning of August until the end of September of 2020.

3.3.3 Semi-structured interviews

The second method used to collect primary data was semi-structured interviews with open-ended questions that allowed participants to describe and reflect on their experiences conducting STEAM research. The interviews were guided by a compilation of pre-determined questions and probing questions, which were subject to modification at the beginning of the interview process. 12 Interviews were conducted via phone and video call to comply with the implemented social distancing measures and travel restrictions. All participants were invited via email and were required to electronically sign an informed consent form to ensure free and fair participation. With the interviewee's consent, the interviews were recorded and then transcribed and translated by the researcher. Interviews were conducted from mid-August until the beginning of October of 2020 and took place in Spanish and English.

3.4 Analysis

This study utilized a deductive and inductive thematic approach for qualitative analysis of translated interview transcripts and open-ended survey responses. Preliminary themes were informed by the literature review and the research objectives and were first manually coded by the researcher. The coding of emerging themes and sub-themes was then carried out using NVivo 12 qualitative analysis software.

4. Findings and Discussion

4.1 *Participant Profile*

The survey and interviews included 12 women, six men and two non-binary individuals. Participants also reflected a diversity across STEM expertise and disciplines and nationalities. Please see Figure 1 for the distribution of nationalities and Figure 2 for the research participants' distribution of STEM expertise.

Methods	Countries	# of participants
Semi-structured interviews	Colombia	8
	Bolivia	3
	Peru	1
Online survey	Brazil	2
	Ghana	1
	Benin	1
	South Africa	1
	Ethiopia	1
	Kenya	1
	Tanzania	1
Total	**10 countries**	**20 participants**

Figure 1

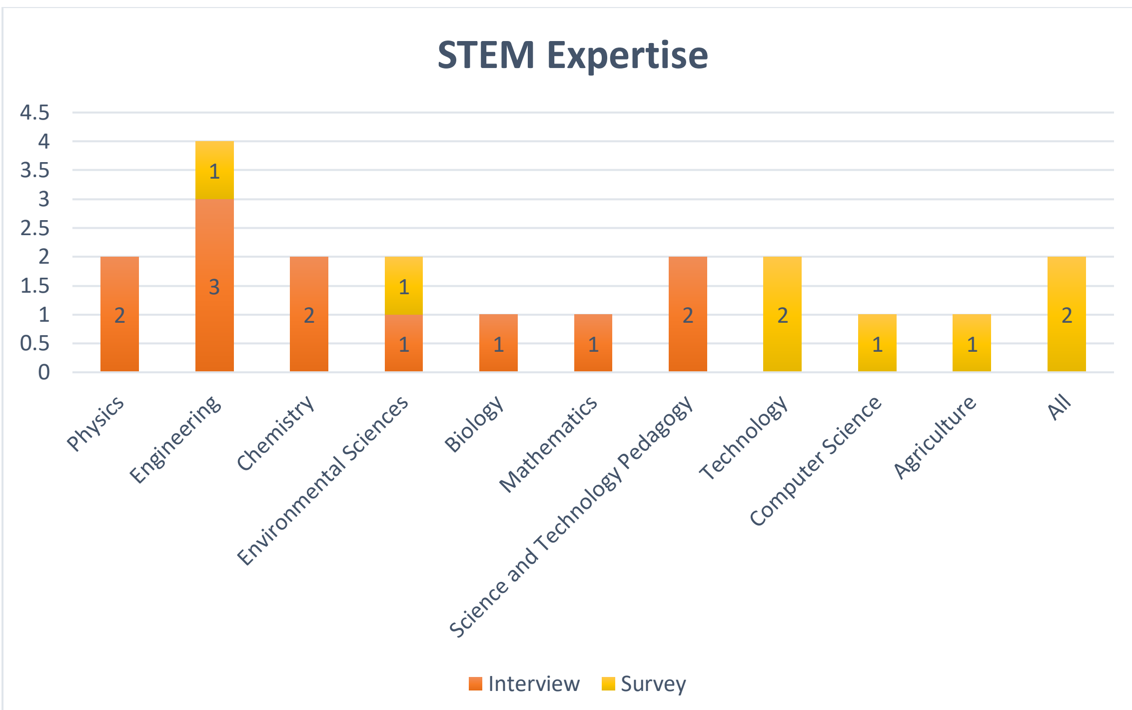

Figure 2

4.2 *STEAM research teams compositions and expertise*

This study called for STEM scientists who had experience employing the Creative and Liberal Arts in their research in any capacity, whether they were trained in both areas or were engaged in STEAM teams that brought together experts from STEM and the Arts. Participants demonstrated a wide range of experiences in incorporating concepts, methods and perspectives from communications, sociology, anthropology, theatre, design, plastic arts, painting, architecture, psychology, economics, and gender studies. As STEAM research teams were most often composed of researchers with specific disciplinary expertise in either the Arts or STEM, participants stated that recruiting researchers with expertise in both fields was a significant challenge when forming research teams:

> "Sometimes it's difficult finding experts in both fields, so we recruit people from each so they can give us a much more integral vision of what we want to analyze […]"

These views emerged mainly in relation to the concern that traditional STEM education does not adequately train and prepare students to become well-rounded researchers. One interviewee highlighted how STEM scientists are trained in an isolated environment that hinders their ability to insert themselves in projects where the scope is beyond the knowledge from their field:

> "[…] it is difficult to talk with engineers, with scientists, with biologists, chemists, and the challenge there is that they have been educated in these paradigms of rigid disciplines, of the disciplines that are not committed to the context and have no relation to it."

A shared experience amongst participants was that of STEM researchers attempting to perform tasks outside of their area of expertise in the early stages of a project without the support of social scientists or artists. This was indicated to be linked to a common belief that STEM scientists possess the capacity to assume each role required to meet the research objects, regardless of if they had not been trained in that specific discipline, as experienced by one engineer:

> "We learned to respect roles because definitely one of the big problems that one encounters in this matter is "everything-ologist". I had commented to you that we did not believe that we would need someone to do any design. In our head, at the beginning of the research, one considers that you can do everything, you can plan, you can develop, you can execute it, and that has gone through the whole team, through all the processes, of course you can train, but it's definitely a lie […]"

However, others recognized the limitations of their skills and knowledge and formed their research teams according to the project's specific requirements. Those who tried to take on concepts from the Arts without the appropriate skills were disappointed when the final products were not well received and did not meet the objectives of the project. Failure to assume multiples roles due to lack of relevant training prompted a critical reflection within teams about the necessity of collaborating with artists and social scientists. One engineer whose team of creative artists and scientists developed and commercialized a pharmaceutical product described their experience with arriving at this realization:

> "[…] in the first instance, they were elements that we required that only came out of us, that is, artistic and that creative part can be developed as an inherent capacity of each of the researchers. And we did [laugh]. I can't tell you that the results were good [laugh]. When we threw that out, the reviews about the product and the entire investigative process were super good, but the image, the design and everything else, was catastrophic […]"

By reuniting discipline-specific experts and researchers with the expertise of both fields when possible, STEAM teams developed multidisciplinary, interdisciplinary, and transdisciplinary collaborations to design, develop, execute and disseminate their research. Multidisciplinary frameworks were not commonly adopted amongst the researchers as they mostly favoured interdisciplinary and transdisciplinary research. This indicates a relatively strong level of engagement between disciplines rather than the minimum level that categorizes multidisciplinarity. STEAM teams that employed methods from the Creative Arts typically assumed an interdisciplinary framework as designers and artists were more involved in the final steps of STEAM initiatives to translate research or render a product more visually pleasing to the target publics. In contrast, transdisciplinary teams from the study generally called for more integral incorporation of components from the Liberal Arts, such as applying a social lens to the conceptual framework, including gender considerations and analysis and engaging with communities. These characteristics illuminate the gap in how the visual arts, performing arts and literary arts are being incorporated in STEM research and application compared to the social sciences and humanities.

4.3 *STEAM research initiatives and representation of marginalized groups*

When looking at how STEAM teams were composed in terms of gender, specifically, the scientists had predominantly been involved in gender-balanced teams or involved mostly women. Few participants had engaged in male-dominated teams or teams with members that identified as neither men nor women. This result is interesting because of the prioritization of expertise before gender identity when forming STEAM teams. The STEM scientists stated that they often relied on their professional networks to find other researchers to engage in their initiative, although there were teams that made active efforts to have a gender balance despite the challenges of finding experts of specific genders:

> "Yes we always try to have a balance but in the African context it is always a challenge because we usually almost always have more men than women."

Applying to secure funding for STEAM research was reported to present opportunities for social inclusion as funding may require gender-balanced teams. One engineer describes how this incentive impacted the inclusion of women in their project:

> "In the project, when we were writing the paper to apply for the funds, yes, we knew that they were going to value gender equity very highly, or that there are equal numbers of women, equal numbers of men. Just as something that is within the components of the research project is basically how you address gender in environment within the research."

Integrating marginalized groups as researchers in STEAM projects was also an issue when recruiting team members as their underrepresentation in higher education poses a barrier. STEAM teams still managed to include female students, students with disabilities, students from low-socioeconomic backgrounds, ethnic minorities and individuals from the LGBTQ community. It is worth noting that the research participants who belonged to diverse teams, especially those that included more women and individuals identifying outside of the gender-binary, commented that the process of recruiting these researchers occurred organically because their distinct perspectives and lived experiences rendered them more attracted to the unconventional questions addressed by STEAM research. Two expert informants expressed this experience:

> "[The team] was formed by Queers, by the weird folk, by nerds, those that are not from [the city], those are from the peripherals but are interested by the Arts in science for example. I don't know, those people just come together. We did a call for those students; they are the people that surround us. And with them, we finished working. I don't know, it's a natural connection."

> "It was natural to include Arts in our STEM research. Mostly because, as women, with different backgrounds, motherhood, gender, and sexual experiences we also lead our personal research and studies through diversified approaches."

Further, one engineer remarked how having a diversity of perspectives created a safe climate and space of exchange where they felt comfortable and included:

> "But, in changing being in a group where there are people who are from different backgrounds, you make psychologist friends, sociologist friends, you are with other engineers, mathematicians, it creates like a neutral environment in which you no longer have the fear to argue, to express your opinions and I think you feel a little more natural. I think that's a... a very interesting aspect of including the Arts within research, that they become STEAM, is that you feel more neutral, you feel more confident as well and, well, that's very helpful for the research project, that people feel more comfortable, [...]"

4.4 *Challenges and best practices of inter and transdisciplinary collaboration*

Several challenges were identified from the interviews and survey responses regarding interdisciplinary and transdisciplinary STEAM research. Among these challenges was the perceived strong divide between the Arts and STEM experts, as echoed in the literature. For instance, one researcher who had not undertaken STEAM research until engaging in their current project described the experience of breaking down the tendency to work in silos in between disciplines to move towards an interdisciplinary approach:

> "I think that we say, "Someone else is going to do it", we think "I only do the technical part" and this is how we have been approaching it in many of the engineering companies. But these last years, in which I was telling you, we have been working more with professionals from other disciplines, we have not realized that it is not so, that it is really necessary to approach a problem in an integral way."

Further, participants discussed the occasional unwillingness of STEAM team members, from either STEM or the Arts, to accept or understand the relevance of different knowledge, methods and concepts than what they are used to applying. By being skeptical about adopting certain aspects from other disciplines, the development of research design and execution would be hindered, despite the necessity of such an incorporation in the projects. It was suggested that these entrenched divides stemmed from negative preconceived notions of other disciplines and those who practiced them:

> " […] I realized that there were certain perceptions that were held about what engineering is, that were accurate, but there were many perceptions that I considered not so accurate, for example, something that came out a lot in the workshop when sociologists especially talked about work in the communities, they were a little bit, like "The engineer was going to tell people what to do". So, it seems that they looked at us as people who tell people what to do, and, really, they always think they are right."

Another prominent challenge that surfaced across countries was the lack of funding opportunities for collaborative STEAM research. Participants stated that science-granting councils, higher education institutions and sciences ministers focused more on providing funding to target disciplinary projects in themes such as health, agriculture and technology. One participant also expressed that the recent pandemic would only accentuate the scarcity of funding available for STEAM research to invest in disciplinary efforts. In contrast to these frustrations, however, it was also suggested that government funding for STEAM research is starting to gain prominence and is becoming more open to funding cross-disciplinary projects:

> "I think there are currently budgets, because the current government policy decided to focus on something that is the creative industries, and within the creative industries, they recognize the participation of art, as it can be to a great extent autonomously, as an artistic practice and to another extent as an instrument of entertainment, or an instrument of ... the dissemination of knowledge. So, I think there is a budget at the moment of medium, medium capacity […]"

There were specific examples of STEAM research best practices that surfaced, such as holding monthly and annual meetings with all members of the project to exchange and communicate ideas in a collaborative way, develop the research design and write the final results together. This practice, although time-consuming, was said to ultimately improve group performance and enhance collaborative work. Additionally, researchers made efforts to establish a transdisciplinary approach to their STEAM teams where both artistic and scientific knowledge could be equally utilized and valued, as illustrated by the following comment:

> "So, as you can see, these are very interdisciplinary projects, even I think, because we work with, we listen to [the social scientists and artists], we take into account what they say in the community, I would even say an approach to transdisciplinary. Because they are part of the same research, and their opinion counts, we take it very much into account, that's the approach I've been working with for the last three years."

One researcher recounted how their training in both the social sciences and STEM allowed them to facilitate the connection between fields to develop such a transdisciplinary dynamic:

> "[…] my training, I have that training of a doctorate in sociology and engineering, so there has always been that bridge between those disciplines, and I am connected with social sciences groups. […]"

In interdisciplinary teams composed of disciplinary-specific researchers, tasks and responsibilities were delineated to specific members to prioritize utilizing their specific skills and knowledge for the purposes of their role:

> " And then, there we learned certain elements and we learned that ... there is a saying, it is said "Shoemaker to your shoes." So, when it arrived, do you know what this saying means? It is that, if you are a smart expert, then all that it means to work in that area, you have to do it. But beyond that, no, because it is not your area."

4.4 *Gender, intersectionality, and socially responsible outcomes*

Despite the aforementioned barriers and challenges, researchers expressed that the outcomes generated from the collaborative STEAM research outweighed these issues. Notably, participants discussed the different ways their research challenges power structures and inequality by first acknowledging and addressing the fact that technologies and innovations are not without bias. Strategies and efforts to challenge power structures differed amongst the research participants' projects depending on the research objectives and scope. STEAM projects that specifically focused on addressing gender equality, for instance, incorporated gender considerations in multiple stages of the research design, included women as research participants and applied a gender-based analysis. The distinct lived experiences within diverse teams was suggested to inspire the decision to undertake a core focus of gender in research. One chemist described this interaction:

> "No, I think that [gender and diversity are] our themes, our battles. We cannot dissociate our academic lives to our activism. Our activism, we must do it from academia, from our methodologies. There is our activism. We do our own activism in the streets, in the marches. They're our lives, we cannot disassociate from what we are."

Participants also discussed that considering gender as a core focus may not always be appropriate depending on whether the research context calls for it and what the project hopes to achieve. Beyond questions of gender, however, social scientists and artists' expertise was also reported to support the adoption of an intersectional approach to incorporate considerations of various marginalized identities, such as race, class, ethnicity, disability, and motherhood within the rationale methodology and analysis. This theme was especially reiterated in the context of conducting research in communities as researchers who possessed extensive knowledge of social and cultural issues allowed STEAM teams to build bridges and foster trust with their research participants. Another chemist whose study investigates the health risks of working with pesticides in local communities explained how they needed to gain the trust of community members to be able to determine the quantity of pesticides in their blood. The following two quotes from this researcher capture their experience working with experts who could connect with the communities:

> "If I had had another approach than I did before, because I had done a similar study alone before not with an interdisciplinary team, well, it was... I got fewer participants in the study before. Because we reach out to the community, we do an explanation and that's it, but now the approach is different thanks to the social sciences. Gaining the trust of the community is very different […]"

> "[…] those who came from sociology, not only had experience in gender issues, but also had experience in studies with different ethnicities, issues of race. So, they already had the issues very clear, they had done research on them, on other issues, but they addressed both gender and race issues."

Moreover, integrating the Creative Arts in designing final products that aimed to be effectively used in societies made them more palatable. Participants discussed how their innovations became more approachable for the public's usage by employing visual artistic concepts. For instance, one transdisciplinary STEAM project is applying an intersectional approach to developing prosthetic limbs for women with physical disabilities and incorporated elements from design to make them aesthetically pleasing and increase the rate at which their target public wore them. The Creative Arts also allowed researchers to address sensitive societal issues, as exemplified by one project that united artists and engineers to create virtual actors that communicated testimonies of real people that disappeared due to the internal armed conflict of the country. This project aimed to help communities heal from the loss of those who are missing and to move forward with coping with the controversial peace accords.

Additionally, it was noted by one engineer that utilizing unconventional knowledge and research methods in and of itself challenged hierarchical notions of knowledge that are so ingrained in scientific institutions:

> "[…] To make visible certain… a bit the invisibility of the evaluation systems that only take into account the product of hegemonic knowledge. So, in that sense there is a discussion about certain practices that we call 'orphan practices', research that isn't recognized, that is invisible. There is potential, but they are not valued by institutions. So, there is a discussion, and also the research on networks to make visible that production of knowledge that can be made in the periphery of networks."

4.5 *Accessible knowledge and outputs through the Arts*

A common application of the Arts in interdisciplinary STEAM innovations and research among the participants was for scientific knowledge translation purposes. Participants discussed how the Arts allowed for a diversification of final products and outputs that are outside of the norms of scientific research products that can only be understood by individuals well-versed in the matter, such as with academic papers and articles.

> "[…] I am not interested in papers. But yes, we have a ton of films, pamphlets… the things that we use to work with communities aren't papers. Videos. Short films. Because we can't arrive there and say we'll write a paper, that does not go through my mind. To not use methods from the Arts would be incongruent. And if we wanted to do a project one day with music, our product would certainly be a song. Or a musical piece. Because if we are working from the Arts, the products must be from the Arts, from design."

Examples of finals products developed by the participants' research teams included murals, paintings, sculptures, theatre pieces, dance performances, poetry, films, graphic design work, and others. This role of the Creative Arts also highlighted the need to recognize and value distinct products as outputs to present research results. One researcher stressed how this diversification calls for a better recognition of the Creative Arts:

> "If we want to validate the space for the Arts, we must start transforming things like that, that products from the Arts aren't papers. And the way of working from the Arts doesn't produce papers, they are pieces, for example graphic design. They are artwork if we're talking about the plastic arts. It's producing short films if we are working with the visual. We cannot be obligated to produce papers. And that's how we work in terms of that connection, of recognizing the value of the Arts. The value of the Arts is in the way in which they are expressed."

Such knowledge translation strategies were said to have been particularly helpful when STEAM teams conducted research in communities where literacy rates are low and scientific papers are impractical in disseminating research results. However, other participants refuted the idea of utilizing the Creative Arts specifically as a medium to disseminate scientific knowledge because of how they are limited to playing a secondary role instead of being embraced for their full creative capacity. This contrarian opinion is demonstrated by the following comment:

> "I think it is misguided to think of the Arts in an instrumental way. It's unfortunate, um ... but it's a very common place, to use the Arts as a dissemination mechanism to convey an idea. Yes? Because there is a subordination of the place of the Arts, the Arts are subordinated to the cognitive plan of science, for example, engineering, technology."

The different beliefs of this use of the Creative Arts reflects what was found in the literature regarding the varying purposes amongst scholars who employ STEAM approaches.

5. Conclusion

The purpose of this study was to generate knowledge on the extent to which STEAM approaches are used to advance research in LMICs and what benefits such approaches bring to the research enterprise in STEM fields, particularly on the underrepresentation of marginalized groups, as well as the production of socially responsible research and innovations. Drawing from the literature and experts' experiences, this study has highlighted the importance of fostering collaborative work between the sciences and Arts to render STEM outputs more humane and inclusive of experiences and groups that have traditionally been excluded from contributing to the production of scientific knowledge. Although coordinating and facilitating multi, inter and transdisciplinary expertise holds significant challenges, such as access to funding, divisions between fields and forming diverse teams, the potential and opportunities that STEAM research can offer are immense.

Echoing what was found in the literature, the research findings point to the increasing need for a diversification of perspectives from various Arts disciplines to contribute to shaping STEM innovations and research that actively challenge the influence of human bias. Moreover, STEAM projects that adopt gender considerations and intersecting factors tend to involve diverse teams of individuals of various intersecting identities, and vice-versa. However, there was also push back against the use of quotas instead of prioritizing the skills and abilities of an individual regardless of gender. Best practices of commonly used inter and transdisciplinary STEAM team dynamics included investing time in monthly or annual team meetings, seminars, and workshops, developing comprehensive frameworks to engage each actor from the relevant disciplines, and delineating tasks and responsibilities based on expertise. Finally, another significant finding that emerged from the interviews and surveys is the use of the Arts to disseminate and translate accessible scientific knowledge to multiple publics and communities.

Taken together, these findings support recommendations for the relevant stakeholders to better support STEAM researchers and diverse women in STEM on distinct institutional levels:

1) Science granting councils, science ministers and higher education institutions to provide multi-year funding opportunities for interdisciplinary and transdisciplinary STEAM research initiatives with specific requirements of gender considerations;
2) Further develop and promote STEM graduate studies or research training initiatives that incorporate the Arts in LMICs higher education institutions, and;
3) Improve methods of collecting gender-disaggregated and intersectional data of workers within STEM institutions for more targeted policies in support of inclusion and diversity.

Notwithstanding its small number of primary informants due in part to COVID-19, this study offers valuable insights into how the questions addressed in multi, inter and transdisciplinary STEAM research may attract researchers of diverse backgrounds, especially female researchers, in LMICs so that their untapped potential may be leveraged. This topic has largely been neglected by the literature thus far; therefore, this study lays the groundwork for much-needed research on the integration of the Creative and Liberal Arts in STEM projects and its implications regarding social inclusion and the production of socially responsible outputs in such undertakings. More broadly, further larger-scale investigation on STEAM research outcomes in LMICs will be crucial for these approaches to become common practice.

6. Acknowledgements

I'd like to thank everyone from the lovely Foundations for Innovation team that provided me with invaluable support throughout the year. I am especially grateful to my mentor Luc Mougeot, who has guided me in various aspects of my professional development, research and academic goals, as well as in my personal life. A special thanks to the inspiring researchers who took the time to participate in this study and provided references, comments, and overall support.

7. References

Bauer, G. (2014). Incorporating intersectionality theory into population health research methodology: Challenges and the potential to advance health equity. *Social Science & Medicine*, *110*, 10–17. https://doi.org/10.1016/j.socscimed.2014.03.022

Bird, S. J. (2014). Socially Responsible Science is More than "Good Science". *Journal of Microbiology & Biology Education, 15*(2), 169-172. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4278471/

Blickenstaff, J. C. (2005). Women and Science Careers: Leaky Pipeline or Gender Filter? *Gender and Education,* 17(4), 369–386. https://doi.org/10.1080/09540250500145072

Bolukbasi, T., Chang, K. W., Zou, J., Venkatesh, S & Kalai, A. (2016). Man is to Computer Programmer as Woman is to Homemaker: Debiasing Word Embeddings. *Cornell University.* https://arxiv.org/pdf/1607.06520.pdf

Bowleg, L. (2012). The Problem with the Phrase *Women and Minorities:* Intersectionality – an Important Theoretical Framework for Public Health. *American Journal of Public Health, 102*(7), 1267-1273. doi: 10.2105/AJPH.2012.300750

Bresnick, J. (2018). *Top 12 Ways Artificial Intelligence Will Impact Healthcare*. Health IT Analytics*.* https://healthitanalytics.com/news/top-12-ways-artificial-intelligence-will-impact-healthcare

Carli, L. L., Alawa, L., Lee, Y., Zhao, B., & Kim, E. (2016). Stereotypes about gender and science: Women ≠ scientists. *Psychology of Women Quarterly, 40*(2), 244–260. https://doi.org/10.1177/0361684315622645

Ceci, S.J., Williams, W.M., 2011. Understanding current causes of women's underrepresentation in science. Proceedings of the National Academy of Sciences. https://doi.org/10.1073/pnas.1014871108

Cheryan, S., Ziegler, S. A., Montoya, A. K., & Jiang, L. (2017). Why are some STEM fields more gender balanced than others? *Psychological Bulletin, 143*(1), 1-35. https://doi.org/10.1037/bul0000052

Choi, B. C., & Pak, A. W. (2006). Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. Definitions, objectives, and evidence of effectiveness. *Clinical and investigative medicine*, *29*(6), 351–364.

Colucci-Gray, L., Burnard, P., Cooke, C., Davies, R., Gray, D. & Trowsdale, J. (2017). Reviewing the potential and challenges of developing STEAM education through creative pedagogies for 21st learning. *British Educational Research Association – Research Commission.* https://jotrowsdale.files.wordpress.com/2017/11/bera-research-commission-report-steam.pdf

Crenshaw, K. (1989). Demarginalizing the Intersection of Race and Sex: A Black Feminist Critique of

Antidiscrimination Doctrine, Feminist Theory and Antiracist Politics. *University of Chicago Legal Forum, 1989*(8). https://chicagounbound.uchicago.edu/cgi/viewcontent.cgi?article=1052&context=uclf

Eaton, A.A., Saunders, J.F., Jacobson, R.K., West, K. (2020). How Gender and Race Stereotypes Impact the Advancement of Scholars in STEM: Professors' Biased Evaluations of Physics and Biology Post-Doctoral Candidates. *Sex Roles*. doi: 10.1007/s11199-019-01052-w

Engendering Success in STEM. (2019). *Intersectionality in STEM*. http://successinstem.ca/wp-content/uploads/2019/10/Intersectionality-in-STEM-Final.pdf

European Commission, and Directorate-General for Research. (2013). Gendered Innovations: How Gender Analysis Contributes to Research. *Report of the Expert Group "Innovation through Gender.* https://ec.europa.eu/research/science-society/document_library/pdf_06/gendered_innovations.pdf

Fehrenbacher, A. & Patel, D. (2019). Translating the theory of intersectionality into quantitative and mixed methods for empirical gender transformative research on health. *Culture, Health & Sexuality*, 1–16. doi: 10.1080/13691058.2019.1671494

Feldsteing, S. (2019). The Global Expansion of AI Surveillance. *Carnegie Endowment for International Peace.* https://carnegieendowment.org/2019/09/17/global-expansion-of-ai-surveillance-pub-79847

Ghanbari, S. (2015). Learning Across Disciplines: A Collective Case Study of Two University Programs that Integrate the Arts with STEM. *International Journal of Education & the Arts, 16*(7), 1-21. https://eric.ed.gov/?id=EJ1069829

Harcourt, W. (2008). Heading blithely down the garden path? Some entry points into current debates on women and biotechnologies. In Women in biotechnology, ed. Francesca Molfino, and Flavia Zucco, 35–69. New York, NY: Springer.

Harwell, D. (2019). *Federal study confirms racial bias of many facial-recognition systems, casts doubt on expanding use*. The Washington Post. https://www.washingtonpost.com/technology/2019/12/19/federal-study-confirms-racial-bias-many-facial-recognition-systems-casts-doubt-their-expanding-use/

Huyer. S. 2015. "Is the gender gap narrowing in science and engineering?" in UNESCO Science Report: towards 2030, 85-103. https://unesdoc.unesco.org/ark:/48223/pf0000235447

IDRC. (2017). *The world needs more women scientists.* https://www.idrc.ca/en/stories/world-needs-more-women-scientists#:~:text=The%20Organization%20of%20Women%20in,low%20and%20middle%2Dincome%20countries.

IDRC. (2019). *Transforming gender relations. Insights from IDRC research*. https://issuu.com/idrc_crdi/docs/wd_13_000_gender_e-file_en?e=34655515/70235030.

Invernizzi, N. & Foladori. G. (2005). Nanotechnology and the developing world: Will nanotechnology overcome poverty or widen disparities? *Nanotechnology Law and Business, 2*(3), 294–303.

Jensen, B. (2020). *How AI and Art Hold Each Other Accountable*. Stanford University. https://hai.stanford.edu/blog/how-ai-and-art-hold-each-other-accountable?utm_source=Stanford+HAI&utm_campaign=3bc405ad0c-EMAIL_CAMPAIGN_2020_09_20&utm_medium=email&utm_term=0_aaf04f4a4b-3bc405ad0c-

Kahane, C. J. (2013). Injury vulnerability and effectiveness of occupant protection technologies for older occupants and women. *National Highway Traffic Safety Administration.* https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811766

Kamdar, B. (2020). *Facebook's Problematic History in South Asia*. The Diplomat. https://thediplomat.com/2020/08/facebooks-problematic-history-in-south-asia/

Kelly, U. A. (2009). Integrating Intersectionality and Biomedicine in Health Disparities Research. *Advances in Nursing Science, 32*(2), 42– 56. doi: 10.1097/ANS.0b013e3181a3b3fc
Khady Lo, N. (2020). Préjugés sociaux et challenges professionnels: les nombreux défis des scientifiques africaines*. BBC.* https://www.bbc.com/afrique/region-54268826
Klein, J. (2019). *Fighting the Gender Stereotypes That Warp Biomedical Research*. The New York Times*.* https://www.nytimes.com/2019/05/30/health/gender-stereotypes-research.html?
Klinge, I. (2010). Innovative Changes in Biomedicine: Integration of Sex and Gender Aspects in Research and Clinical Practice. In GenderChange in Academia, edited by Birgit Riegraf, Brigitte Aulenbacher, Edit Kirsch-Auwärter, and Ursula Müller, 231–42. Wiesbaden: VS Verlag für Sozialwissenschaften.
Lachman, R. (2018). *STEAM not STEM: Why scientists need arts training*. The Conversation*.* https://theconversation.com/steam-not-stem-why-scientists-need-arts-training-89788
Land, M. H. (2013). Full STEAM Ahead: The Benefits of Integrating the Arts Into STEM. *Procedia Computer Science* 20: 547–52.
Ludwig, M. J., Boyle, A, & Lindsay, J. (2017). Review of Evidence: Arts Integration Research Through the Lens of the Every Student Succeeds Act. *American Institutes for Research.* https://www.wallacefoundation.org/knowledge-center/Documents/Arts-Integration-Research-Every-Student-Succeeds-Act-ESSA.pdf
Marr, B. (2018). *How is AI Used in Education - Real World Examples of Today and a Peek Into the Future.* Forbes*.* https://www.forbes.com/sites/bernardmarr/2018/07/25/how-is-ai-used-in-education-real-world-examples-of-today-and-a-peek-into-the-future/?sh=19dbda85586e
Miller, C. C. (2016). *As Women Take Over a Male-Dominated Field, the Pay Drops.* The New York Times*.* https://www.nytimes.com/2016/03/20/upshot/as-women-take-over-a-male-dominated-field-the-pay-drops.html
Miles, T. (2018). *UN investigators cite Facebook role in Myanmar crisis.* Reuters. https://www.reuters.com/article/us-myanmar-rohingya-facebook-idUSKCN1GO2PN
Moss-Racusin, C.A., Dovidio, J.F., Brescoll, V.L., Graham, M.J., Handelsman, J., (2012). Science faculty's subtle gender biases favor male students. *Proceedings of the National Academy of Sciences.* https://doi.org/10.1073/pnas.1211286109
Nanowerk. (2012). *Nanotechnology for development.* *https://www.nanowerk.com/spotlight/spotid=24927.php*
The New York Academy of Sciences. (2014). *The Global STEM Paradox*. https://www.nyas.org/media/15805/global_stem_paradox.pdf
Nielson, M. W., Bloch, C. W. & Schiebinger, L. (2018). Making gender diversity work for scientific discovery and innovation. *Nature Human Behaviour, 2,* 726-734. https://www.nature.com/articles/s41562-018-0433-1
Nikoleyczik, K. (2012). Towards Diffractive Transdisciplinarity: Integrating Gender Knowledge into the Practice of Neuroscientific Research. *Neuroethics*, *5*(3), 231–245. https://doi.org/10.1007/s12152-011-9135-3.
OECD. (2015). Girls' lack of self-confidence, in *The ABC of Gender Equality in Education: Aptitude, Behaviour, Confidence,* OECD Publishing, Paris. doi: https://doi.org/10.1787/9789264229945-6-en
Okeke, Iruka N., Chinedum P. Babalola, Denis K. Byarugaba, Abdoulaye Djimde, and Omolaja R. Osoniyi. (2017). Broadening Participation in the Sciences within and from Africa: Purpose, Challenges, and Prospects. *CBE—Life Sciences Education, 16*(2). doi: 10.1187/cbe.15-12-0265
Orange, E., Weiner, E., & Ranasinghe, E. (2018). *10 Trends to Watch in 2018 & Beyond*. Omidyar Network.https://www.omidyar.com/sites/default/files/file_archive/10%20Trends%20to%20Watch%20in%202018%20&%20Beyond_Omidyar%20Network.pdf.
Perignat, E. & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative

literature review. *Thinking Skills and Creativity, 31*, 31-43. https://doi.org/10.1016/j.tsc.2018.10.002
Roy, D. (2016). Neuroscience and Feminist Theory: A New Directions Essay. *Signs, 41*(3), 531–552. https://doi.org/10.1086/684266.
Salamanca-Buentello, F., Persad, D. L., Court, E. B., Martin, D. K., Daar A. S. & Singer, P. A. (2005) Nanotechnology and the Developing World. *PLOS Medicine, 2*(5). https://doi.org/10.1371/journal.pmed.0020097
Schiebinger, L. (2014). Gendered Innovations: Harnessing the Creative Power of Sex and Gender Analysis to Discover New Ideas and Develop New Technologies. *Triple Helix, 1*(9). https://doi.org/10.1186/s40604-014-0009-7
Segarra, V. A., Natalizio, B., Falkenberg, C. V., Pulford, S., and Holmes, R. M. (2018). STEAM: Using the Arts to Train Well-Rounded and Creative Scientists. *Journal of Microbiology & Biology Education, 19*(1). doi: 10.1128/jmbe.v19i1.1360
Settles, I. H., Cortina, L. M., Malley, J. and Stewart, A. J. (2006). The Climate for Women in Academic Science: The Good, The Bad and The Changeable. *Psychology of Women Quarterly, 30*(1), 47-58. https://doi.org/10.1111/j.1471-6402.2006.00261.x
Serrato, R. & Meyer-Resende, M. (2018). *AI can't fix Facebook.* Politico*.* https://www.politico.eu/article/facebook-myanmar-rohingya-opinion-ai-cant-solve-facebooks-problems/
Smith, M. & Neupane, S. (2018). Artificial intelligence and human development: toward a research agenda. *International Development Research Centre.* http://hdl.handle.net/10625/56949
Spelke, E. S. (2005). Sex Differences in Intrinsic Aptitude for Mathematics and Science? A Critical Review. *American Psychologist, 60*(9), 950–958. https://doi.org/10.1037/0003-066X.60.9.950
Tannenbaum, C., Ellis, R. P., Eyssel, F., Zou, J., and Schiebinger, L. (2019). Sex and Gender Analysis Improves Science and Engineering. *Nature* 575 (7781), 137–46. https://doi.org/10.1038/s41586-019-1657-6
Trades Union Congress. (2017). *Personal protective equipment and women: Guidance for workplace representatives on ensuring it is a safe fit.* https://www.tuc.org.uk/sites/default/files/PPEandwomenguidance.pdf
Tschopp, M. (2018). *Psychology of Artificial Intelligence. Foundations, Range, Implications from a Humanities Perspective*. SCIP. https://www.scip.ch/en/?labs.20180215
Udén, M. K. (2017). Implementing Feminist Theory in Engineering: Obstacles within the Gender Studies Tradition. *European Journal of Engineering Education, 42*(3), 336–48.
UNESCO. (2017a). *Cracking the code: Girls' and women's education in science, technology, engineering and mathematics (STEM).* https://unesdoc.unesco.org/ark:/48223/pf0000253479
UNESCO. (2017b). *Measuring Gender Equality in Science and Engineering: Working Paper 2, the SAGA Toolkit*. https://unesdoc.unesco.org/ark:/48223/pf0000259766.
UNESCO. (2017c). *10 Facts about Girls and Women in STEM in Asia.* https://bangkok.unesco.org/content/10-facts-about-girls-and-women-stem-asia
UNESCO. (2018). *Measuring Gender Equality in Science and Engineering: The SAGA Survey of Drivers and Barriers to Careers in Science and Engineering. Working Paper 4.* https://unesdoc.unesco.org/ark:/48223/pf0000266146.locale=en.
UNESCO. (2019). *Women in Science.* http://uis.unesco.org/sites/default/files/documents/fs55-women-in-science-2019-en.pdf
Universities Canada. (2016). *From STEM to STEAM.* https://www.univcan.ca/media-room/media-releases/from-stem-to-steam/
Wajngurt, C. & Sloan, P. J. (2019). Overcoming Gender Bias in STEM: The Effect of Adding the Arts

(STEAM). *InSight: A Journal of Scholarly Teaching, 14,* 13-28. https://files.eric.ed.gov/fulltext/EJ1222869.pdf

Wang, M. T. & Degol, J. L. (2017). Gender Gap in Science, Technology, Engineering, and Mathematics (STEM): Current Knowledge, Implications for Practice, Policy, and Future Directions. *Educational Psychology Review, 29*(1), 119–140. https://doi.org/10.1007/s10648-015-9355-x

Webb, P., Young, J., & Webb, P. (2005). Perhaps It's Time for a Fresh Approach to ICT Gender Research? *Journal of Research and Practice in Information Technology, 37*(2), 147–160.

Weatherhead, E., Gearheard, S., and Barry, R. G. (2010). Changes in Weather Persistence: Insight from Inuit Knowledge. *Global Environmental Change, 20*(3), 523-28.

West, S. M., Whittaker, M. & Crawford, K. (2019). *Discriminating Systems. Gender, Race, and Power in AI*. *AI* Now Institute*.* https://ainowinstitute.org/discriminatingsystems.html.

Zimmerman, A. S. (2017). The STEAM Inherent in STEM: A Mathematical Example. *The STEAM Journal, 3*(1). *https://scholarship.claremont.edu/steam/vol3/iss1/13/*